



**Faculty of Mechanical Engineering**

**INVESTIGATION OF WARPING DEFORMATION BY STARCH  
ADHESION IN FUSED DEPOSITION MODELLING 3D PRINTER**

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**INVESTIGATION OF WARPING DEFORMATION BY STARCH ADHESION IN  
FUSED DEPOSITION MODELLING 3D PRINTER**

**MUHAMMAD AFDHAL BIN NAZAN**

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**2021**

## DECLARATION

I declare that this entitled “Investigation of Warping Deformation by Starch Adhesion in Fused Deposition Modelling 3D Printer” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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## **APPROVAL**

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

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## ABSTRACT

Nowadays, Fused Deposition Modelling (FDM) is the most widely used rapid prototyping process in the market. Many derivatives of FDM are open source designs with variety of design complexity and printing quality. The output of open source FDM 3D printers are not perfect due to molten plastic filament tend to shrink, warps and peeled away from the printer's bed during fabrication process. Many researchers came across these problems and found that it was due to the internal shrinkage during plastic solidification, uneven heat distribution of printing bed and short curing time. The study of the use of adhesive on the printer bed especially on countermeasures using starch base adhesive are limited. Hence the purpose of this research is to investigate the effectiveness of starch based adhesives material as countermeasure for warping deformation problems. Four different starch adhesives based material of cassava, sago, soy, and rice were applied to printing bed before extrusion of PLA filament. This is intended for comparison with synthetic adhesive which are normally applied in FDM process. The prepared standard geometries were printed for tensile strength analysis and surface morphology analysis. In addition, comparison of starch based adhesives and synthetic adhesive were perform by warping deformation measurement for 3D printed flat bar model and complex geometry model. Both models were printed with and without the existence of heat bed. For flat model, four side corners were measured while for complex model, the effect of curling, overhang, internal shrinkage and side shrinkage were inspected. Furthermore a design and development process of an automatic adhesive spreader to the Prusa i3 FDM 3D printer was proposed and the effect of curling, overhang, internal shrinkage and side shrinkage between the new spreader and conventional method were established. The result of experiments shown that cassava based adhesive has achieved the greatest tensile strength among the starch based material and achieved the lowest warping deformation compares to sago, corn and rice based. The evaluation on flat bar model shows average errors in between 15.13% to 22.77% for starch based adhesives compare to 3.80% error for synthetic adhesive. However, improvement can be seen when heat bed was applied to printing bed where starch based adhesives shown to have average warping deformation errors in between 2.51% to 3.92%. While for complex model, other warping deformation effects of curling, overhang, internal shrinkage and side shrinkage shown similar improvement when heat bed were applied to the initial setup. Lastly, the automatic adhesive spreader has been successfully built and performed at a better result compare to the conventional method which used a scrapper tool. The deformation values has reduce to 0.13% for curling effect, 1.92% for overhang effect, 0.09% for internal shrinkage effect and 0.28% for side shrinkages effect. As conclusion, the starch based adhesion materials especially cassava can improve warping deformation of curling, overhang, internal shrinkage and side shrinkage. Moreover, applying heat on bed has proven as one of major factor of improving starch based adhesion in reducing the warping deformations. In addition, the automatic adhesive spreader had shown significant improvement to reduce warping deformation effects. Thus, heat bed and this spreader are important and they are needed to take into account in conducting future experiments.

# **KAJIAN UBAH BENTUK LEDINGAN DENGAN REKATAN KANJI TERHADAP PENCETAK 3D PEMODELAN PEMENDAPAN TERLAKUR**

## **ABSTRAK**

*Pada masa kini, Pemodelan Pemendapan Terlaktur (FDM) merupakan proses prototaip pantas yang paling banyak terdapat di pasaran. Kebanyakan FDM adalah terdiri daripada reka bentuk sumber terbuka di mana terdapat kepelbagaian kualiti cetakan dan kompleksiti rekaan. Keluaran daripada pencetak 3D FDM adalah tidak sempurna disebabkan oleh leburan filamen plastik yang cenderung untuk mengecut dan meleding dari dasar pencetak semasa proses fabrikasi. Ramai penyelidik telah menjumpai masalah ini dan mendapati ia adalah disebabkan oleh pengecutan dalaman semasa pemejalan plastik, haba teragih secara tidak sekata pada dasar pencetak dan tempoh rawatan yang pantas. Kajian menggunakan perekat pada dasar pencetak terutamanya dengan menggunakan perekat kanji adalah terhad. Maka tujuan kajian ini adalah untuk mengkaji kebolehcetakan perekat kanji bertindakbalas menyelesaikan masalah ubahbentuk ledingan. Empat jenis kanji berasaskan ubi, sagu, soya dan beras telah disapu kepada dasar pencetak sebelum penyemperitan filamen PLA. Ia bertujuan untuk perbandingan dengan perekat sintetik. Geometri berpiawai dicetak untuk analisis kekuatan tegangan dan analisis morfologi permukaan. Perbandingan di antara perekat berasaskan kanji dan sintetik telah dijalankan melalui pengukuran ubahbentuk ledingan model 3D bar rata dan model geometri kompleks. Kedua-dua model ini dicetak dengan kewujudan dan tanpa kewujudan pemanas haba. Untuk model bar rata, empat sisi telah diukur manakala untuk model kompleks, kesan ikalan, juntaian, pengecutan dalaman dan pengecutan luaran telah diperiksa. Selain itu, satu proses rekabentuk dan pembangunan penyebar perekat automatik yang pada model pencetak 3D Prusa i3 telah dicadangkan dan kesan ikalan, juntaian, pengecutan dalaman dan pengecutan luaran di antara penyebar automatik dan penyebar konvensional telah diperolehi. Keputusan ujikaji menunjukkan perekat ubi telah mencapai kekuatan tegangan terbesar dan ubah bentuk ledingan yang paling rendah di kalangan kanji yang lain. Penilaian terhadap model bar rata menunjukkan purata di antara 15.13% ke 22.77% bagi perekat kanji berbanding 3.80% untuk perekat sintetik. Bagaimanapun, peningkatan boleh dilihat apabila pemanas haba diletakkan dan perekat kanji menunjukkan purata di antara 2.51% hingga 3.92%. Untuk model kompleks pula, ubah bentuk ledingan seperti ikalan, juntaian, pengecutan dalaman dan pengecutan luaran menunjukkan pembaikan yang serupa apabila pemanas haba dipasang. Akhir sekali, penyebar perekat automatik berjaya dibina dan beroperasi pada hasil yang lebih baik daripada kaedah konvensional iaitu pengikis. Nilai ubah bentuk telah berjaya diturunkan kepada 0.13%, 1.92%, 0.09% dan 0.28% untuk setiap kesan ubahbentuk ledingan. Sebagai kesimpulan, bahan-bahan perekat berkanji terutamanya ubi menunjukkan pengurangan ubah bentuk. Selain itu, penggunaan pemanas haba telah dibuktikan sebagai salah satu faktor utama dalam memperbaiki ubah bentuk ledingan. Tambahan lagi, penggunaan pemanas haba di dasar pencetak juga terbukti menjadi faktor utama dalam mengurangkan ubahbentuk ledingan. Perekat automatik telah menunjukkan peningkatan ketara dalam mengurangkan kesan ledingan. Oleh itu, pemanas haba dan penyebar ini adalah penting dan perlu diambil kira dalam kajian pada masa hadapan.*

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## LIST OF ABBREVIATIONS

3D	- Three dimensional
ABS	- Acrylonitrile butadiene styrene
AM	- Additive manufacturing
ASTM	- American society for testing and materials
BTCA	- Butane tetra carboxylic acid
CAD	- Computer aided-design
DFM	- Design for manufacturing
DTMA	- Dynamic thermal and mechanical analyser
DSB	- Defatted soy-flour based
FDM	- Fused deposition modelling
FFF	- Fused filament fabrication
LOM	- Laminated object manufacturing
MAP	- Mussel adhesion protein
MEM	- Melt extrusion manufacturing
NASA	- National aeronautics and space administration
PF	- Phenol-formaldehyde
PLA	- Poly-lactic acid
PVA	- Poly-vinyl alcohol
RP	- Rapid prototyping
SBR	- Styrene butadiene rubber

SEM	- Scanning electron microscope
SGC	- Solid ground curing
SHP	- Sodium hypophosphate
SLA	- Stereo lithography
SLS	- Selective laser sintering
STL	- Stereo-lithography
TDI	- Toluene disco-cyanate
TPS	- Thermo Plastic Starch
UF	- Urea-formaldehyde

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# CHAPTER 1

## INTRODUCTION

### 1.1 Background of project

Fuse Deposition Modelling (FDM) is one of Additive Manufacturing (AM) technology that has been developed in early of 1970s by Stratasys (Anderson et al., 2018). The technology has drawn an attractive attention to the manufacturing process industries by providing simple ways to automatically produce products with high dimension accuracy and in rapid time. According to Alsoufi et al. (2019), the process done by applying reverse engineering concepts where no additional conventional tooling such cutting, milling and drilling are involved.

Besides that, the FDM technology is rapidly developed and proven its effectiveness especially in designing and production as highlighted by Kruth et al. (1998) and Galantucci et al. (2015). The AM technology should help a lot to reduce time wasted to build prototypes, physical models, and finished parts from 3D CAD drawing. It allows the fabrication even for complex shapes using layer by layer approach with minimum adjustment (Villalpando et al., 2014 and Martorelli et al., 2016).

The primary applications of AM technology are for visual aids, presentation models and rapid prototype (RP). However, the requirement for the applications in AM are mostly related to consideration of dimensional accuracy, surface roughness and general appearances. Most of error in accuracy observed in the final part arises from shrinkage during cooling and solidification that uneven the temperature gradient heat distribution. It has created internal stress within a part as mentioned by Peng (2012) and Anhua and Xingming (2014). In the extreme cases, stress is produced by thermal gradient that cause

the parts delaminated or cracked (Wang et al., 2017). Hence, the geometrical error shaped on the product need to be solved first before utilising them in the mass production condition. It is widely to believe that FDM has good potential in future of manufacturing field.

## **1.2 Problem statement**

One of the drawback that hampered the FDM 3D printer is the plastic filament that came out from nozzle tends to shrink and sometimes it peeled away from the printing bed (Alsoufi et al. 2018). This problem is well known as warping deformation in the FDM printer especially for a low cost open source FDM 3D printer and it been emphasized by many researchers such as Atar et al. (2010), Noriega et al. (2013), and Mostafa et al. (2015). According to Dimitrov et al. (2006) and Alsoufi et al. (2019), when the thermoplastic state material become cold, the internal stress may create warping deformations especially around the corner. This deformation affects the geometrical dimensions such height and width of the printed part. However, the warping deformation could be reduced by taking into account several factors such user experiences, printing preferences and parameters (Song and Telenko, 2017), and also applying adhesive material such synthetic glue onto the printing platform (Alsoufi et al. 2019). However, no information has been published yet on the use of starch based adhesives to reduce the deformation issues in enhancing the printing quality and the printing failure. Apart from that, in the conventional method, a scrapper is used to spread the adhesives over the printing bed. Somehow, the adhesive is not spread evenly onto the surface due to several factors. As a result, the bonding between filaments are weak and warping occurs. A new